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by Bedford A. Lampkin and Robert J. Randle

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SUMMARY

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The Ames Midcourse Navigation and Guidance Simulator has been used for defining problem areas associated with sextant sightings in a space navigation scheme, and for determining the relative accuracy of sextant sightings taken with a hand-held sextant and with a gimbaled sextant. Sightings of this type would be used for determining the trajectory of a translunar or an interplanetary vehicle.

The data indicate that, while the sextants used in this investigation require refining, they could probably be incorporated into a space navigation system. While the gimbaled sextant was slightly favored over the hand-held sextant, the hand-held sextant provided nominally as accurate sighting data as did the gimbaled sextant.

Within the limitations of this study there was little effect of vehicle rotational motion about a single axis on sighting repeatability.

AUTHOR

INTRODUCTION

The sextant is the classic symbol of the art of navigation. This instrument was originally developed to meet the demands of nautical navigation and in later years was modified for aerial navigation. For both nautical and aerial navigation, the sextant has proven to be reliable for accurately measuring the angle between two lines of sight (one line of sight is typically to the horizon while the second line of sight is to some selected celestial objects). The maximum precision typically required for an instrument used in these techniques is 1 minute of arc.

With the advent of manned space flight, attention has been focused on the instrument required for space navigation. For manned space flight, reliability is of prime importance and accuracy requirements of the instrument in this capacity are stringent, possibly having to meet a standard deviation of 10 seconds of arc (ref. 1). Based on preliminary analyses conducted at the Ames Research Center and on the results of reference 2, it appeared that a study was warranted to examine the use of a hand-held sextant in the manned spacecraft navigation problem.

An evaluation of the instrument effectiveness in an operator-instrument combination is typically conducted statistically. Though the operator-instrument combination may have been optimized so as to reduce large consistent errors, some errors still occur randomly in the measurement process. In the process of evaluation it is necessary to determine the characteristics of these random errors and determine the repeatability of the measured values. Measurement repeatability may be defined about the mean measured values or an absolute measured value. While the instrument repeatability about the absolute measured value is required for a definitive evaluation of the instrument, significant economy in time and effort can be realized if the mean measured value is used in a preliminary evaluation of the operator-instrument combination or in comparing near-similar operator-instrument combinations. In this study the repeatability of measurements about the mean measured value has been used to determine the effect of several environmental conditions on operator-instrument effectiveness as well as to compare the performance of operators with two different instruments.

The purpose of this investigation was to explore the effects of some environmental conditions on manual sextant performance for a typical space navigation task. Results comparing the sighting performance of a hand-held and a gimbaled sextant for oscillatory spacecraft motions have been obtained. Further conditions that have been examined are the effects of pressure-suit helmet visor, and the comparison of performance when sighting real stars as opposed to simulated stars.

Seven subjects participated in this investigation. Three were Air Force navigators[1] temporarily assigned to Ames Research Center.

TEST EQUIPMENT

The Ames Midcourse Guidance and Navigation Simulator

The basic components of the Ames Midcourse Guidance and Navigation Simulator (figs. 1 and 2) are a visual scene that simulates a moon-star field and, 40 feet in front of the scene, a cab that simulates a space vehicle capable of carrying three occupants. As indicated in figure 1, the cab communicates with an analog computer and with an IBM 7094 digital computer through the appropriate analog-to-digital or digital-to-analog converters.

The visual scene consists of those stars down to fifth magnitude contained in a 25° arc of the sky. Also included is a moon model illuminated to simulate a quarter moon phase. Of the 66 stars simulated in the scene, 6 are collimated. One of the collimated star installations is shown in figure 3. The collimated star consists of a 6-inch parabolic mirror mounted at the end of a fiber-glass tube with a light source located at the mirror's focal point. The light source is a grain-of-wheat lamp enclosed within a metal capsule with a 0.0005-inch hole pointing at the mirror. The uncollimated stars consist of the same type of grain-of-wheat lamp, emitting light through a 0.005-inch hole pointing at the cab. In all cases the brightness of the star is regulated by

[1]These navigators are instructors assigned to the 3535th Navigation Training Wing, Mather Air Force Base, Sacramento, California, and were: Captain Frederick Vosper, Captain Billy Hall, and First Lieutenant Bradford Tilford.

the voltage applied to the lamp (0-2.5 volts). The moon is simulated by a 12-inch commercially available hemispherical moon model.

The cab consists of a three-man crew compartment mounted on an air bearing. The interior volume and shape of the cab approximate the command module of a lunar vehicle. Figure 4 is a photograph of the cab mounted on the air bearing. The spherical air bearing allows the cab to rotate about all three axes with low restraining torques and serves as a gimbal constraint upon the rotational center. The geometry of the bearing (radius of curvature of the bearing surfaces = 52-1/2 in.) placed the center of rotation in the approximate center of the cab. Lead weights are provided such that the center of gravity may be varied from a position below the center of rotation to a position coincident with the center of rotation. During this investigation the center of gravity was well below the center of rotation, making the cab behave much like a pendulum. The size of the bearing limited the cab rotation to $\pm 15^{\circ}$ of pitch and roll. Instrumentation wiring restricted the yawing to $\pm 90^{\circ}$ and also provided small restoring torques about the yawing axis. The instrumentation in the cab provides typical flight information, and a three-axis hand controller is used to control the movement of the cab. Figure 5 is a photograph of the interior of the cab; there are no windows.

Cab motions are regulated by cold gas reaction jets located so as to operate about the three cab axes. The cab rotational acceleration is varied by two different sized nozzles located at each station as well as by a pressure regulator within the cab. The pressurized air required for operating the jets is contained in four tanks on board the cab. These four tanks as well as the nozzle stations acting about the yaw and roll axes can be seen in figure 4. The jets can be operated remotely by analog computer circuitry or manually from within the cab.

Sextants

The conventional marine sextant is a device for measuring the angle between a celestial body and the sea horizon. Unlike the air navigator's bubble sextant with its artificial horizon, the actual sea horizon and the body of interest are seen in the telescopic view of the marine sextant. This feature adapts it naturally to the space navigation sighting task of determining the angle between lines of sight to two celestial objects.

Two different types of sextants were used in this investigation. One type was the Navy Mark II Mod 0, hand-held sextant shown in figure 6. This sextant weighs approximately 2.7 pounds. The vernier readout least count is 0.1 minute of arc. The three-power telescope has a 10° field of view. There is a reticle within the telescope for centering the field of view and for consistently focusing the simulated stars.

A second sextant of this type was adapted to a support mechanism which allowed rotation about the sextant's three major axes (fig. 7). The pitch and yaw axes of the gimbals were approximately 2 inches from the eye and the roll axis passed through the center of the telescope. There were two handles attached to the sextant to facilitate rotational control. The gimbals were also designed so that the telescope could be exchanged conveniently between the gimbaled and hand-held sextant.

The Navy sextants were available early in this study, but later a more effective instrument became available. This second type of instrument, a Plath-Micrometer sextant (fig. 8), is hand-held and has three interchangeable telescopes with magnifying powers of 2.5, 4.0, and 6.0. With the telescope attached to the sextant the total weight was 3.4, 3.6, and 3.7 pounds, respectively. The least count readout of this sextant's vernier scale is 0.2 minute of arc; however, interpolations to 0.1 minute of arc are convenient. The telescopes for this instrument do not have reticles.

Pressure-Suit Helmet

During a portion of the investigation, the subjects wore the helmet of the Navy Mark IV, Mod I full pressure suit. This helmet is equipped with a clear plastic visor that rotates, covers the facial opening, and locks in place to allow the suit to retain its pressure. The visor may also be rotated to a position clear of the facial opening. Figure 9 shows a subject wearing the helmet with visor over the facial opening while sighting the Plath sextant.

TEST PROCEDURES

Task Description

The task in this study was to view a simulated or real star directly through the sextant primary (horizon) line of sight and superimpose upon this image a second star seen through the secondary line of sight provided by a system of mirors properly indexed. Stars were thought to be probably the best targets with which optimum human performance could be most conveniently assured. The stars were collimated or focused as if infinitely far away so that the star line of sight would not move when the cab was rotated.

Performance Criteria

Sighting performance was evaluated by two different methods, the most effective being the standard deviation of the measurements about the mean value of the measured angle. A second method utilized the subjective opinion rating scale shown in figure 10.

No attempt was made to define the absolute angle between the lines of sight of the two simulated stars because of the uncertainty in this measurement, and because the star lines of sight vary with time, up to approximately 2 arc seconds per hour. It was considered that an adequate test of relative performance was the measurement repeatability about the mean measured values. Index corrections were not applied to the data.

The opinion rating scale of figure 10 was adapted from the Cooper rating scale for pilot opinion on aircraft handling qualities; however, only the number scale and the corresponding descriptive phrases slightly modified were used (columns 2 and 4).

Test Subjects

The subjects participating in this investigation were taken from two populations. Three were currently rated Air Force navigation instructors, assigned for two-week periods to Ames Research Center. Five were professional employees working in related investigations at Ames Research Center. Each Air Force navigator participated in the investigation twice for two-week periods while only one professional employee participated upon two occasions for two-week periods. Each two-week period is termed a study cycle. The schedule of the subjects' participation is shown in the table below.

Study cycle	Subject	
	Military	Ames
1	A	B
2	C	D
3	E	F
4	A	G
5	C	H
6	E	G

The subjects were not required to have any particular experience or physical ability to participate.

Training and Motivation

All subjects were given training prior to participating in the testing phase. Though the navigators had extensive experience in the use of bubble sextants, they had not previously used the marine sextant. In most cases the first six days of each two-week testing period were devoted to training. Training sessions were conducted in the morning and afternoon. One and one-half hours was sufficient time to allot to each training session. Twenty-four measurements divided equally among four test conditions were obtained during each training session. Sighting conditions were adjusted so that at the end of training a nearly equal number of sightings had been taken under each test condition.

An effort was made to insure a high degree of motivation in the subjects. Two subjects participated in each two-week session to provide an element of competition. The subjects were fully briefed as to the purpose and scope of the study and importance of their performance in the interpretation of the experiment's outcome. Daily records of the subjects' performance were posted. Each subject was limited to 12 sightings under any one of the several conditions to minimize boredom.

Test Conditions

During this investigation consistent test conditions were maintained except as noted in the following discussion:

<u>Study cycle 1</u>.- The subject, seated in the cab, made sightings with the cab both fixed (zero yaw rate) and undergoing limit cycle oscillations about the yaw axis. The amplitude of oscillation was $\pm 6^{\circ}$. The maximum rates of sinusoidal oscillation were $\pm 1/2^{\circ}$/sec, $\pm 1^{\circ}$/sec, and $\pm 1\text{-}1/2^{\circ}$/sec. Spurious oscillations about other axes were damped to relatively small amplitudes. When the cab was in the neutral position for the yawing oscillation the subject was facing the midposition relative to the target stars. The measurement plane of the target stars was near vertical, with the stars approximately 15° apart.

The conditions under which sightings were obtained are indicated in the table below.

Sextant	Maximum rates of oscillation, deg/sec	Amplitude, deg	
		Cycle 1	Cycles 2,3,4
Hand-held	0		
	1/2	±6	±2
	1	±6	±2
	1-1/2	±6	±2
Gimbaled	0		
	1/2	±6	±2
	1	±6	±2
	1-1/2	±6	±2

Of the 10 days in this study cycle, 6 were devoted to training and 4 to obtaining the data for analysis. During the last 4 days the subjects obtained 24 sightings in the morning and 24 sightings in the afternoon, each group of 12 successive sightings being taken under a particular test condition. The groups of test conditions were presented in random order.

<u>Study cycle 2</u>.- During this study cycle, the test conditions were increased to 16 by the addition of star targets oriented horizontally. The angle between the horizontally oriented stars was approximately 22° and between the vertically oriented stars, approximately 10°.

The cab dynamics differed from those of study cycle 1 by a decrease in oscillation amplitude from 6° to 2°. Yawing rates remained the same.

<u>Study cycle 3</u>.- In this study cycle the cab dynamics remained the same as in study cycle 2. The target star conditions returned to those of study cycle 1, wherein only one pair of target stars were utilized and they were oriented vertically.

Study cycle 4.- The test conditions of study cycle 4 were similar to those of study cycle 3; however, at the conclusion of each group of 12 sightings under specific test conditions, each subject was asked to rate the task difficulty on the basis of the rating scale shown in figure 10.

Study cycles 5 and 6.- On three different nights during each study cycle, the subjects measured the angles between real stars with both the Navy hand-held and gimbaled sextants shown in figures 6 and 7, respectively. The stars chosen were typical navigation stars of first to second magnitude and, while different stars were used at different times, the included angle between stars was seldom over 10°.

Also during study cycles 5 and 6 sightings were obtained in the simulator with the subjects wearing the helmet of a Navy Mark IV, Mod I full-pressure suit and sighting with the Plath-Micrometer sextant shown in figure 8. Sightings were conducted of simulated stars with the subjects wearing the helmet with the visor rotated to a position above the facial opening and with the visor covering the facial opening and locked in place. When the visor was in the down position, oxygen was bled into the helmet at a low pressure to preclude the possibility of anoxia as well as to keep the view clear of condensed water vapor. All three telescopes with magnifying powers of 2.5, 4.0, and 6.0 were used. The cab was fixed with zero oscillation during all sightings.

RESULTS AND DISCUSSION

Training

It had been determined prior to this study that about two weeks of practice sighting sessions were required for a subject to have a consistent level of performance. Though the Air Force navigators had previous experience using the bubble sextants, the elements of the sighting task used in this investigation were quite different from those of sighting with a bubble sextant; consequently they too required approximately the same amount of training as the other subjects. The level of performance reached by either the Air Force navigators or professional employees was nominally the same.

Figure 11 shows the average of the standard deviations of the group of seven subjects obtained in the first four study cycles for each day of the two-week period. Performance improved continuously during the two-week period except for the small regression after the weekend. It had been previously determined that this would occur after the weekend rest, so an additional day of training was provided to restabilize performance.

The extremes of subject variability are indicated in figures 12 and 13. Figure 12 shows the variation over a two-week period of the average of the standard deviation with the greatest variability for a single individual. The day-by-day performance variability decreased during the second week; however, at the end of two weeks the standard deviation of sightings for this subject was greater than 0.4 minute of arc. Figure 13 shows the same type of information except this individual's data showed the least variability over the two-week period. At the end of two weeks the subject's standard deviation of sightings was approximately 0.22 minute of arc. The general trend in either case was for continuous improvement during the two weeks. The mean value of standard deviation (fig. 11) was approximately 0.32 minute of arc.

Figure 14 shows the range of the daily averages of standard deviation for the seven subjects during the first four study cycles. This figure demonstrates that with experience in the sighting task over a wide range of variables, the subjects show decided improvement; particularly, the variability in individual performance decreases from a range of 0.36 to 1.30 minutes of arc of standard deviation on the first day, to a range of 0.22 to 0.46 minute of arc of standard deviation at the end of the second week.

All subjects were tested with a commercially obtained "Ortho-Rater" for visual acuity, the scores of which converted to a Snellen equivalent (ref. 3) ranged from 20-18 (better than average) to 20-40 (poor acuity) for both near and far vision. There is no apparent correlation between visual acuity scores and sighting performance.

Test Results

In figure 15(a) the results from the first study cycle are given, showing the variation of the standard deviation for each subject with increase in yaw rate. In figure 15(b) the individual subject data are averaged to show a performance comparison for the gimbaled and hand-held sextant. Even with subject A exhibiting a smaller sighting deviation than B, their variation in performance with increasing yaw rate is very similar. A comparison between the performance with the hand-held and gimbaled sextant shows that, whereas the standard deviation with the hand-held sextant is constant as yaw rate is increased, the performance with the gimbaled sextant degenerates, reaching a maximum standard deviation at a yawing rate of 1°/sec. This may be explained by the experimental conditions. With an oscillation amplitude of $\pm 6^{\circ}$, the gimbaled sextant was moved out of the range of the collimated beam emanating from the simulated stars at the limits of oscillation. During these periods the simulated stars were not observed for the entire oscillation, thus markedly increasing the difficulty of the task. With the hand-held sextant the subjects were free to move the sextant position so as to keep the star targets in sight during the entire oscillation.

Figure 16 gives the data from study cycle 2. Figures 16(a) and 16(b) show the variation, with increasing yaw rate, of the standard deviation of sighting repeatability for two individuals with both a hand-held and a gimbaled sextant for star targets oriented vertically and horizontally, respectively. In figure 16(c) values of standard deviation have been averaged to demonstrate the effects of sighting targets oriented in a horizontal plane and in a vertical plane. There is an apparent advantage to using targets oriented in a vertical plane. In figure 16(d) standard deviations have been averaged to show the variation with increasing yaw rate of the standard deviation of sighting repeatability for subjects C and D, using the hand-held and gimbaled sextants. Finally in figure 16(e) data obtained from the individual subjects have been averaged to show the variation of standard deviation with increasing yaw rate for performance with the hand-held and gimbaled sextants. There is apparently no significant effect of type of sextant nor does performance degrade with an increase in yaw rate.

The information in figure 17 for study cycle 3 is similar to that in figure 16. Again there is little to recommend the gimbaled sextant in favor of the hand-held sextant and the sighting performance does not degrade with an increase in yaw rate.

Data are presented in figure 18 from study cycle 4 in a fashion similar to the presentation in figure 17. In study cycle 4 the performance of subject A is excellent with the gimbaled sextant, while his performance with the hand-held sextant is not so good as his performance during study cycle 1. It was discovered that subject A, during study cycle 4, had been operating the hand-held sextant with the sextant resting on his knee. This posture destroyed the more natural hand-eye coordination and is probably responsible for the poor performance level.

Figure 19 is a summary of the data from the first four study cycles and indicates the variation of the average of all values of standard deviation of sighting repeatability. Figure 19 indicates equal performance with either sextant and no loss in performance with an increase in yaw rate.

During cycle 4 the subjects used a rating scale (fig. 10) for estimating the difficulty of the tasks. The scale is adopted from the Cooper rating scale for pilot opinion on aircraft handling qualities (ref. 4). There are obvious difficulties in using a subject rating scale which was designed for a quite different task environment. However, only the number scale and the corresponding descriptive phrases were used (columns 2 and 4). It was not attempted to make the descriptive phrases more definitive because of the different experience of the subjects prior to this investigation. The results are given in figure 20. Higher ratings are indicated by lower number assignments. There was a slight preference indicated for the gimbaled sextant, as well as a slight increase in estimated task difficulty with increasing yaw rate.

In study cycles 5 and 6 sighting scores were obtained with real stars as targets. In figure 21 the variation of the standard deviation obtained with real stars during three different sighting sessions is given. The variation of the mean value of standard deviation is shown in figure 21 for values obtained with the hand-held and gimbaled sextant. For comparison the mean values of standard deviation obtained statically with simulated stars are also shown in this figure. Apparently with sufficient experience, sighting repeatability obtained with real stars would compare favorably with scores obtained using simulated stars. This comparison argues for the validity of research information obtained with simulated stars.

The targets were all familiar navigation stars ranging in magnitude from -1.6 to +1.7 and the measured angles were approximately from 5° to 30° oriented in a vertical plane. The time spent in an individual measurement task was similar for both simulated and real stars. One particular operational problem noted by all the participants in this exercise was the uncomfortable and fatiguing posture which the operator of the hand-held sextant must assume and maintain when sighting at two stars both of which are at a high angle above the horizon. For this reason the results shown in figure 21 may not reflect the true potential of this type of instrument.

During study cycles 5 and 6, the subjects wore a pressure-suit helmet and used the Plath-Micrometer sextant (fig. 8) with varying powers of telescope magnification. Figure 22 gives the variation of the standard deviation of these sightings with telescope magnification. The mean value of standard deviation decreased from approximately 0.38 with a 2.5 power telescope to 0.26 with a 6.0 power telescope (a decrease of 30%). The data in this figure were obtained while the subject was sighting through the visor of the pressure-suit helmet (fig. 9) and also with the visor in an open position. It is expected that with further training under the test conditions, the variability in performance data of figure 21 would be considerably decreased.

In study cycles 5 and 6 the subjects wore the pressure-suit helmet and sighted both through the visor as shown in figure 9 and with the visor rotated clear of the facial opening in the helmet. Incremental values of standard deviation of sighting repeatability and of mean measured angles due to use of the visor were obtained and are defined as follows:

Increment of mean measured angle = measured angle with visor down

- measured angle with visor up

and

Increment of standard deviation = standard deviation with visor down

- standard deviation with visor up

For these data the mean measured angle is the mean value of 12 measurements. Each increment is a result of two values both of which were obtained by the same individual during a single study cycle. Figure 23 gives the variation of these incremental values with the three powers of magnification used with the Plath-Micrometer sextant. The visor appeared to affect both the measured angle and the standard deviation in a similar manner. The incremental values of measured angle and standard deviation reached a maximum with a telescope power of 4.0 and was near zero with telescope powers of 2.5 and 6.0.

During this exercise the telescope eyepiece was equipped with a foam rubber ring to cushion it against the plastic visor and to prevent slipping. When the visor is used with the sextant, the telescope eyepiece cannot contact the eyesocket area but must be held away from the face. This increases fatigue and reduces hand-eye coordination, thereby increasing the difficulty in aiming the telescope. The telescope field of view is also reduced, increasing the difficulty of field-of-view orientation and target identification. Increasing the telescope magnifying power generally reduces the field of view and increases the velocity across the field of view at which objects move due to spurious movements of the telescope.

Subject opinion ratings are presented in figure 24 for sightings made with the three Plath-Micrometer telescopes and with and without the pressure helmet visor in place. Subject opinion indicates a general desirability for increased telescope magnification. The sighting task was rated as more difficult through the visor but even with the visor the task was rated less difficult when the telescope power was 4.0 instead of 2.5; however, this opinion reversed itself when the telescope power was increased from 4.0 to 6.0. Evidently with the 6.0 power telescope, the field of view was sufficiently limited that the subjects generally could not utilize the instrument effectively.

In addition to the opinion rating scale of study cycle 4, subjective comments were obtained from each of the test participants at the conclusion of each study cycle. The purpose of these comments was to improve the motivation of the subjects by increasing their participation in the experiment and to offer constructive criticism of the test and the simulation. Many criticisms that occurred consistently at the beginning of training decreased or vanished with experience and training. Body fatigue was a factor often mentioned as affecting the sighting performance, particularly during the training phase of the test; however, as the subjects gained confidence and familiarity with the task, these criticisms decreased. Some subjects felt that arm rests to carry the weight of the arms and the sextant while sighting with the hand-held sextant would be advantageous; however, it could generally be demonstrated that arm rests compromised hand-eye coordination and resulted in reduced sighting performance.

Several practical suggestions concerned the interior lighting of the cab to reduce glare and spurious images within the sextant. There were also practical suggestions in the formulation of a standardized sighting and readout technique. Standardized procedures were required so that results from a number of situations and individuals could be more directly compared.

It was noted that experienced subjects preferred to have the cab interior lighting at such a level that they could conveniently operate the sextants with both eyes open. This preference is usual in a number of sighting tasks, such as aiming a rifle, and reduces eye strain as well as possible pupil distortion caused when the muscles are contracted to squint or close the unused eye.

CONCLUSIONS

The characteristics of a manual sextant sighting task have been investigated in the Ames Midcourse Guidance and Navigation Simulator. The study of the sighting task with the hand-held sextant and a gimbaled sextant under static and dynamic conditions was the primary purpose of this investigation; however, the effect upon performance when sighting real stars, the sextant telescope magnifying power, and effects of sighting through the clear visor of a pressure-suit helmet were also briefly investigated. From a consideration of the data, the following conclusions are presented:

1. Within the limitations of the cab motions reported (yawing oscillations with amplitudes of $\pm 2^{\circ}$ and maximum rates up to $1\text{-}1/2^{\circ}$/sec), the sighting performance was little affected by oscillatory motion of the cab.

2. While according to the subject opinion rating scale the gimbaled sextant was slightly favored over the hand-held sextant, the hand-held sextant provided nominally as accurate sighting data as the gimbaled sextant with less associated mechanical complexity and weight.

3. Increasing the sextant telescope magnifying power from 2.5 to 6.0 decreased the standard deviation of sighting repeatability approximately 30 percent.

4. Sighting through the visor of a pressure-suit helmet increases the difficulty of the sighting task and decreases the accuracy.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., March 1, 1965

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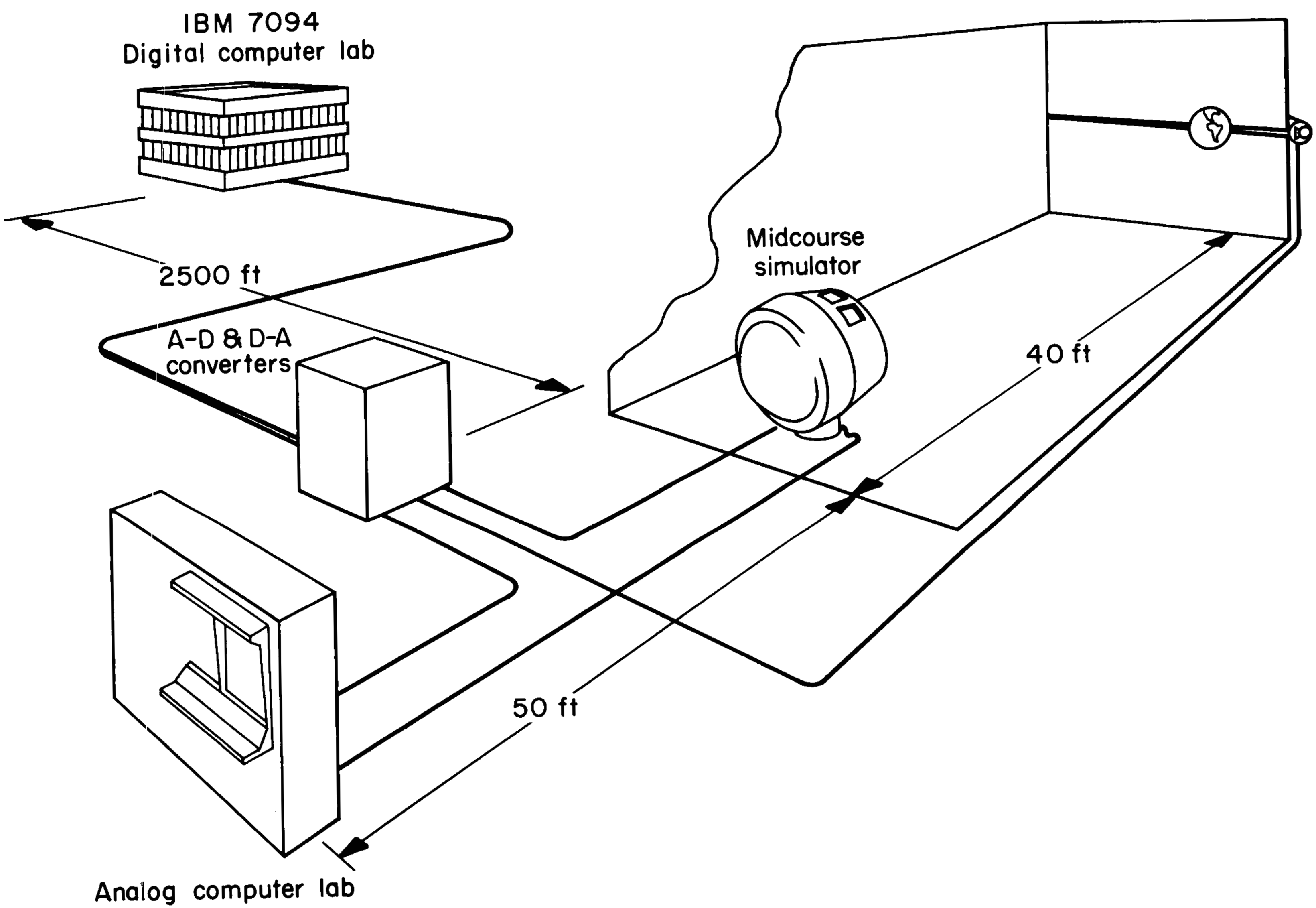

Figure 1.- Major components of Ames Midcourse Navigation and Guidance Simulator.

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Figure 2.- The Ames midcourse simulator.

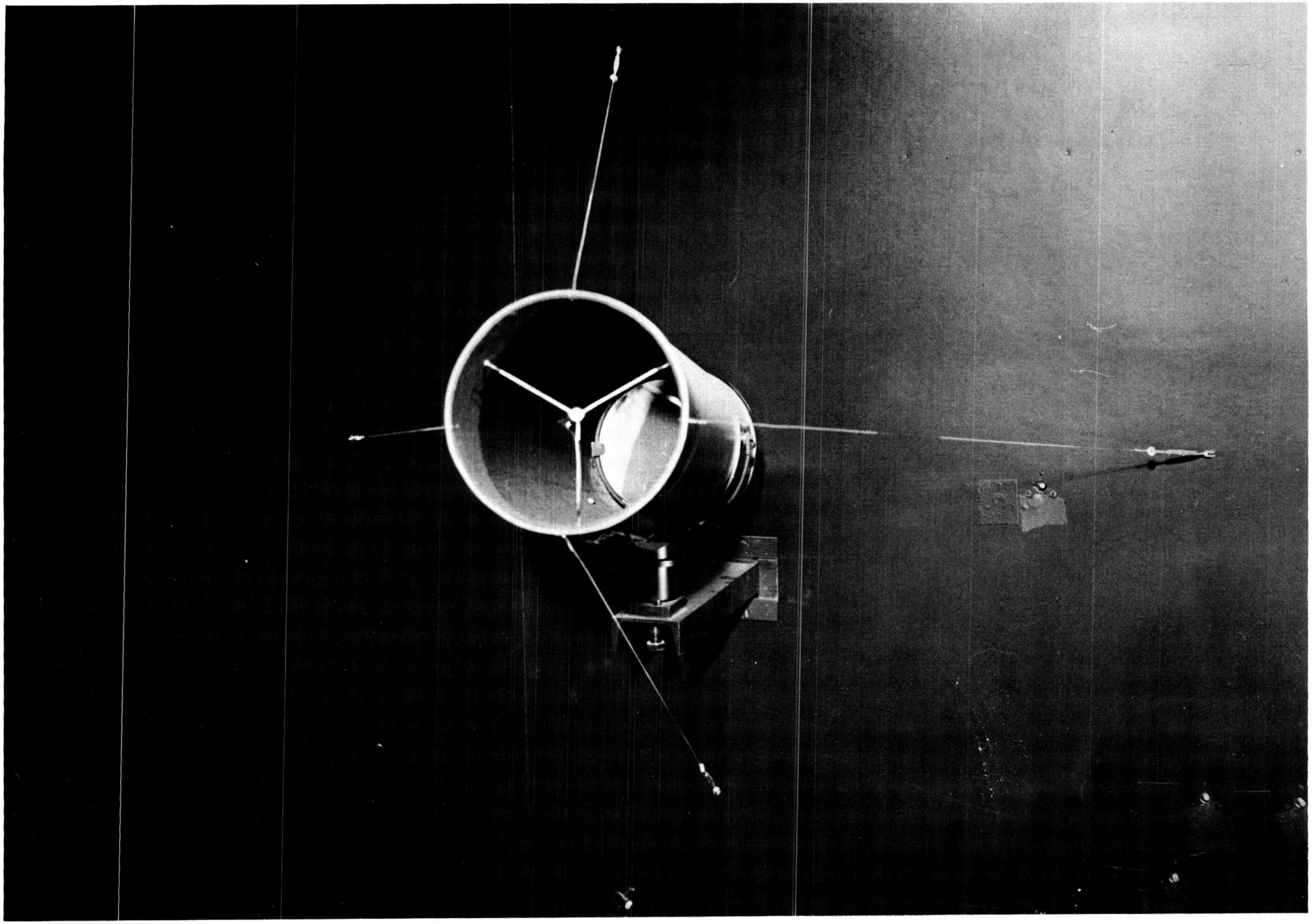

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Figure 3.- Collimated point light source installation.

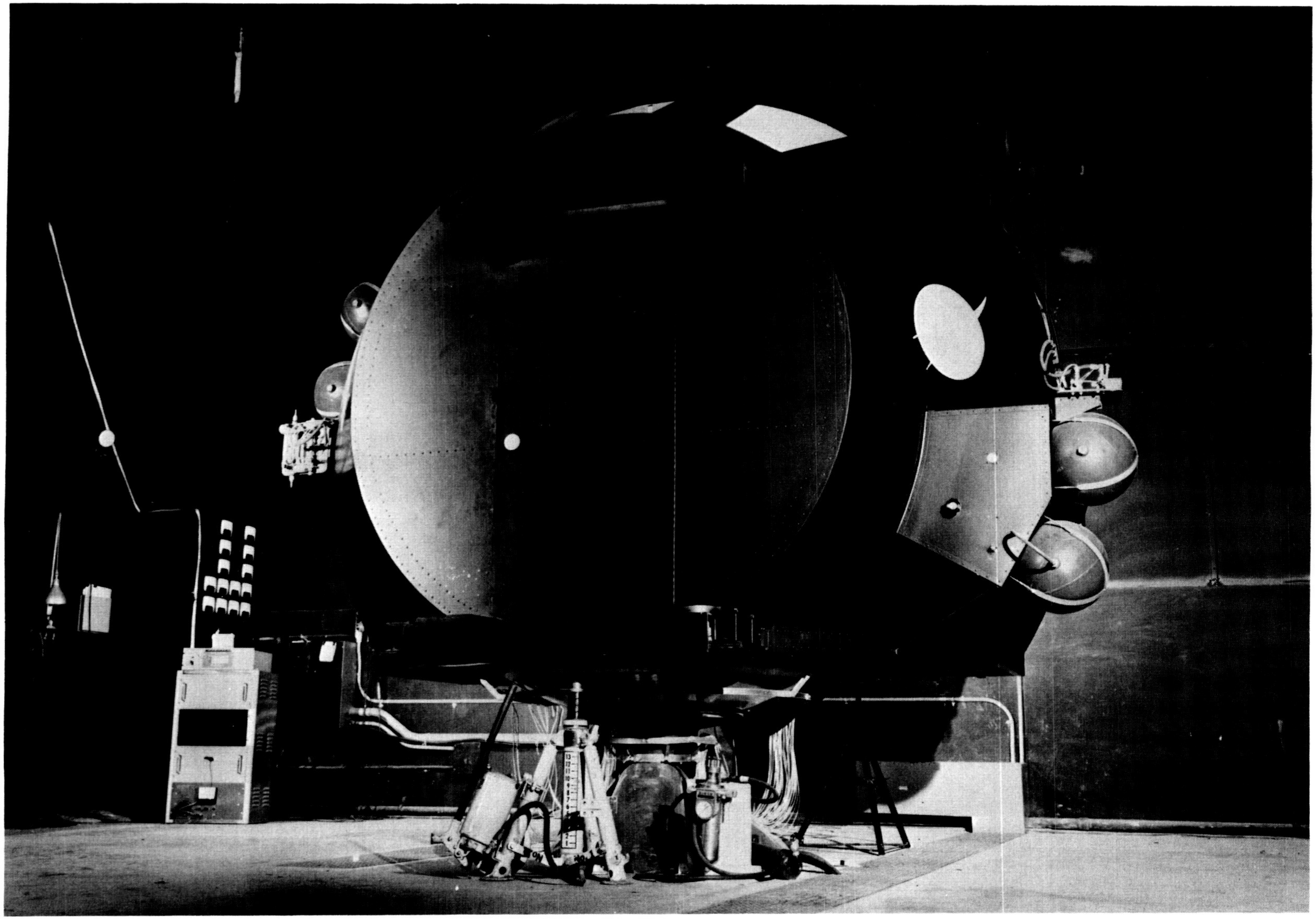

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Figure 4.- The simulator cab and its air bearing.

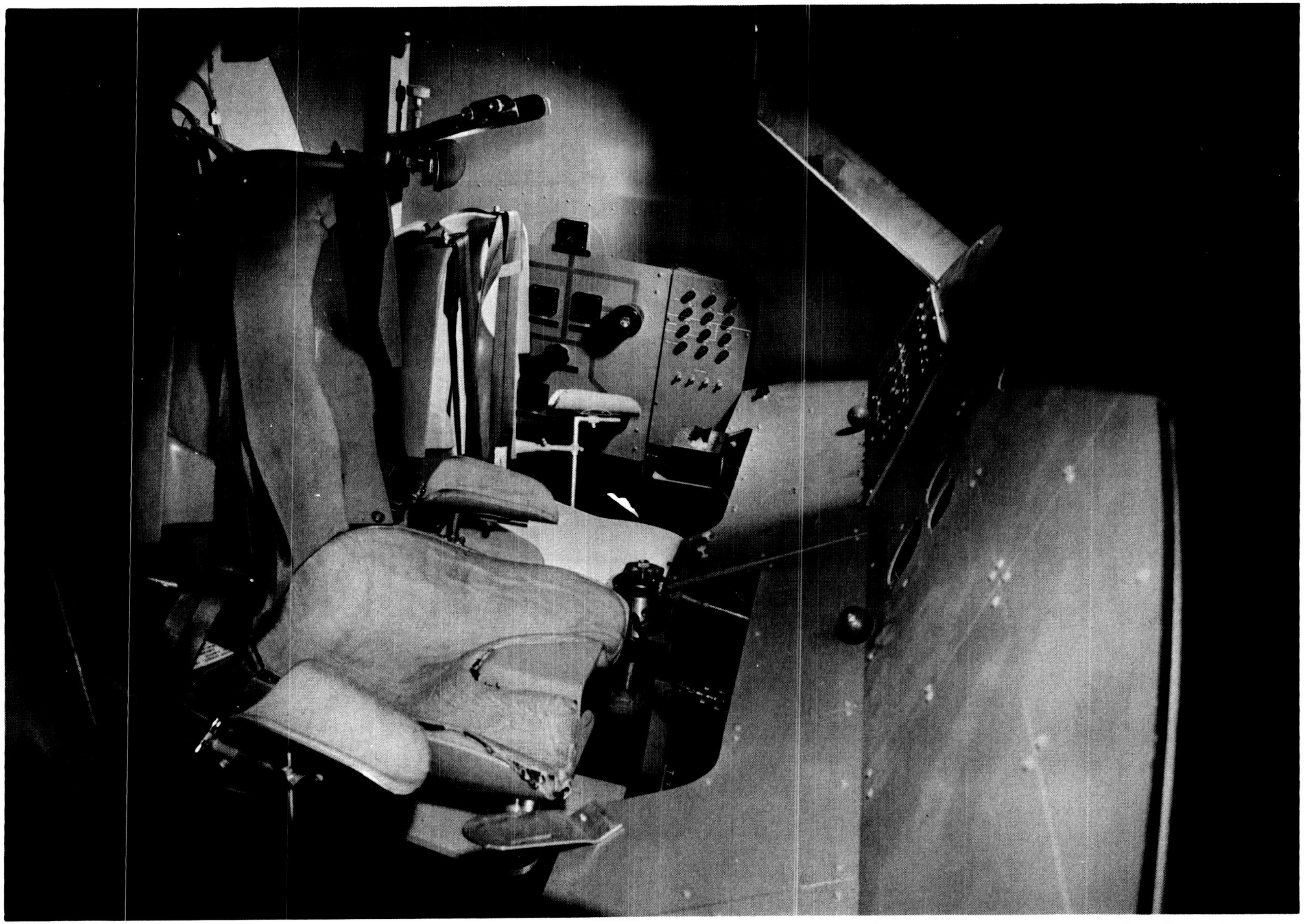

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Figure 5.- Interior of the simulator cab.

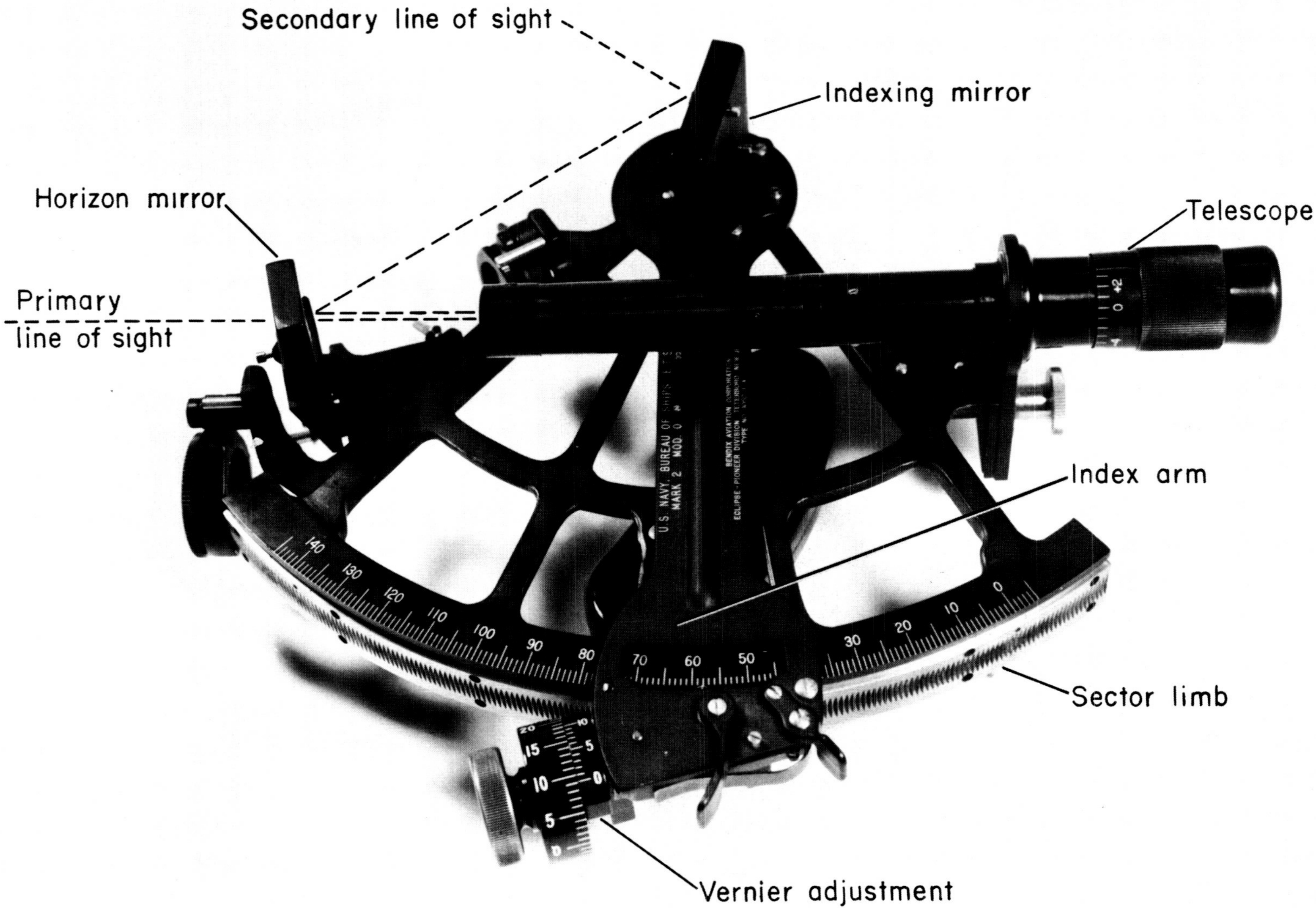

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Figure 6.- Navy Mark II Mod 0 hand-held sextant.

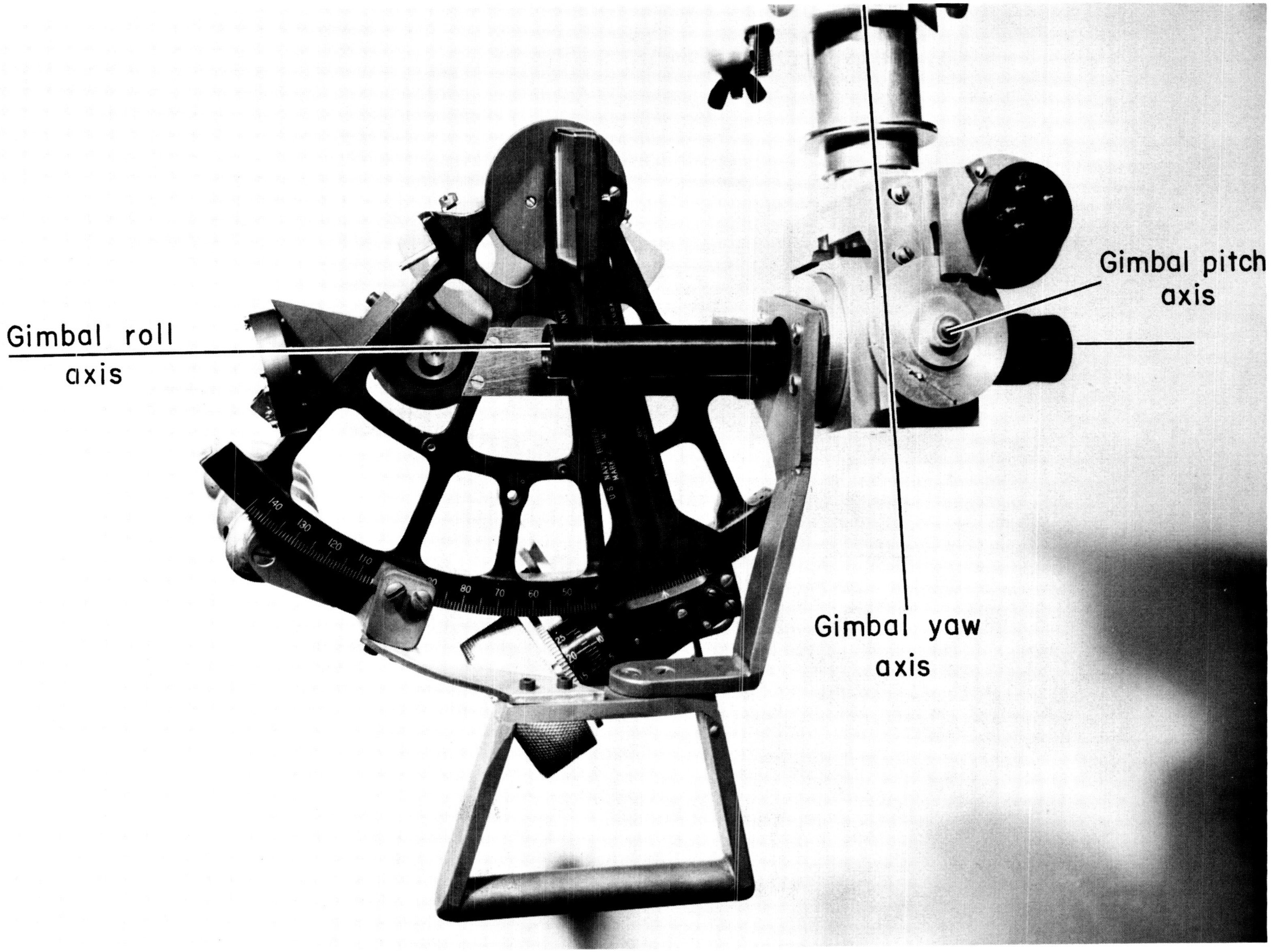

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Figure 7.- A hand-held sextant adapted to the mechanism attached to the cab allows rotational freedom about the instrument's three main axes.

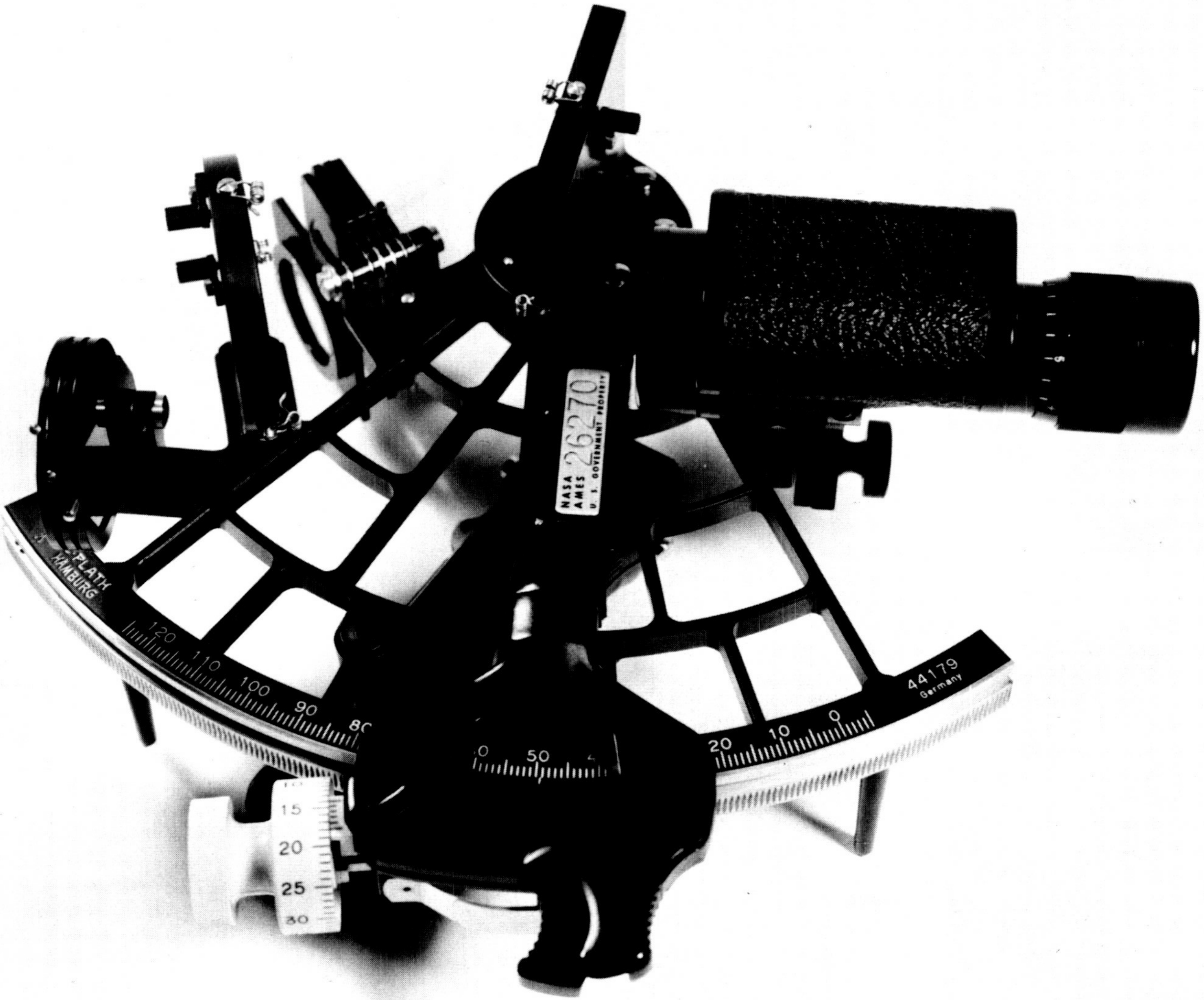

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Figure 8.- Photograph of the Plath-Micrometer sextant.

A-29724-33.1

Figure 9.- Photograph showing the sighting technique with the pressure suit helmet being worn and with the visor in place over the facial opening.

	Adjective rating	Number rating	Description	Primary mission accomplished
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes
		2	Good, pleasant operation	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes
		5	Unacceptable for normal use	Doubtful
		6	Acceptable for emergency use only	Doubtful
No operation	Unacceptable	7	Unacceptable even for emergency operation	No
		8	Unacceptable unable to obtain data confidently	No
		9	Unable to obtain data	No

Figure 10.- Navigator opinion rating scale.

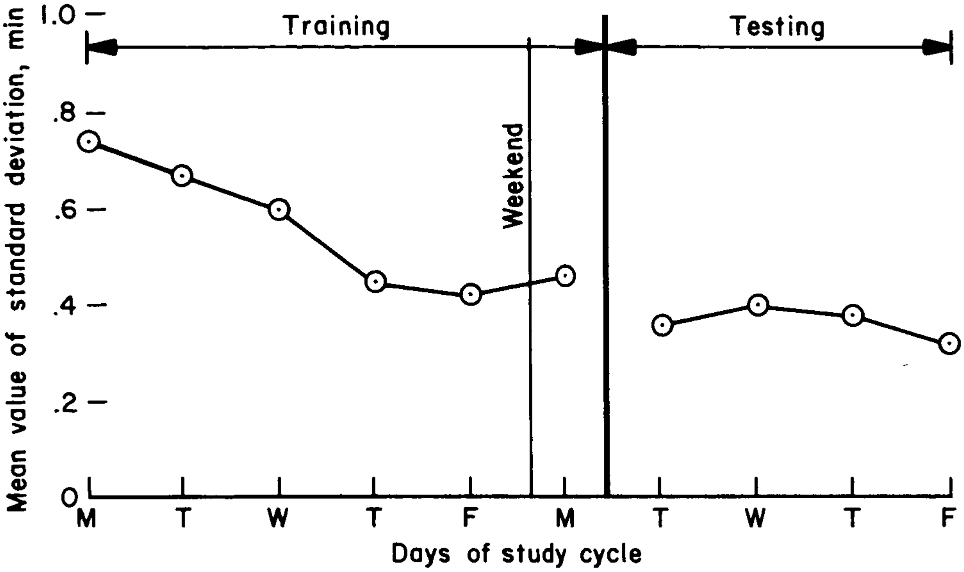


Figure 11.- Mean daily standard deviation for all subjects during training.

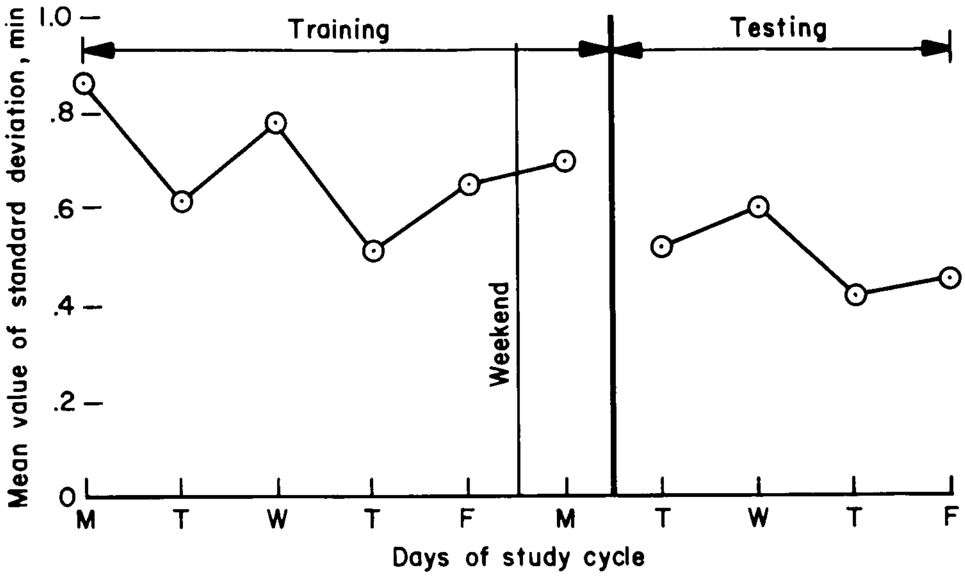


Figure 12.- Daily average of most variable subject.

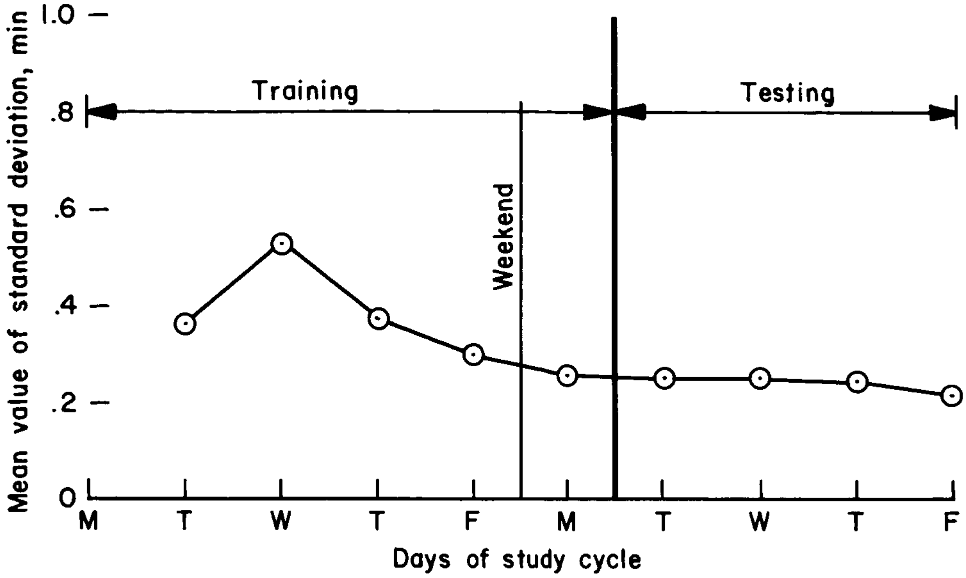


Figure 13.- Daily average of least variable subject.

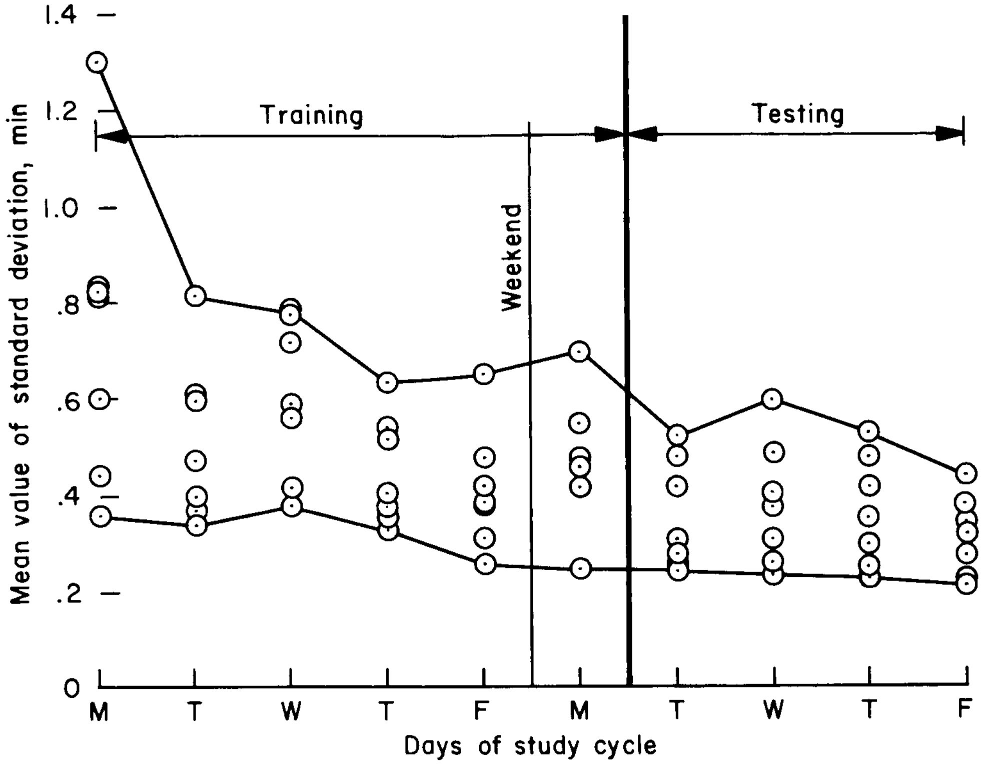
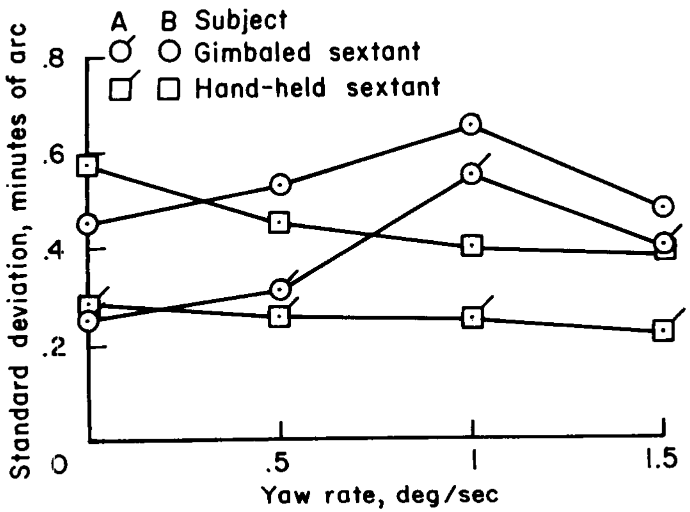
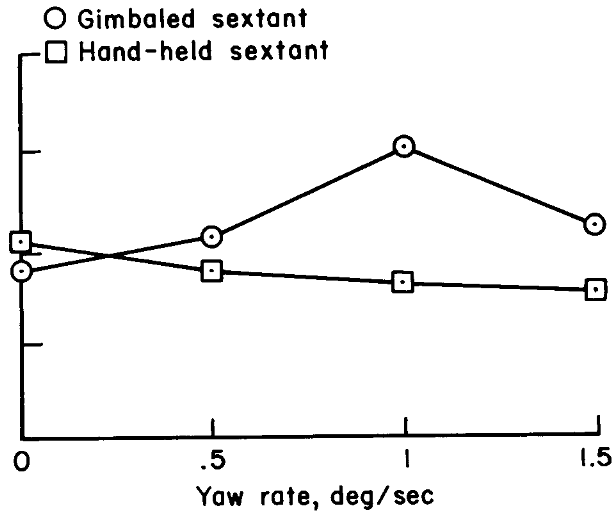


Figure 14.- Range of standard deviations for seven subjects by days during training.

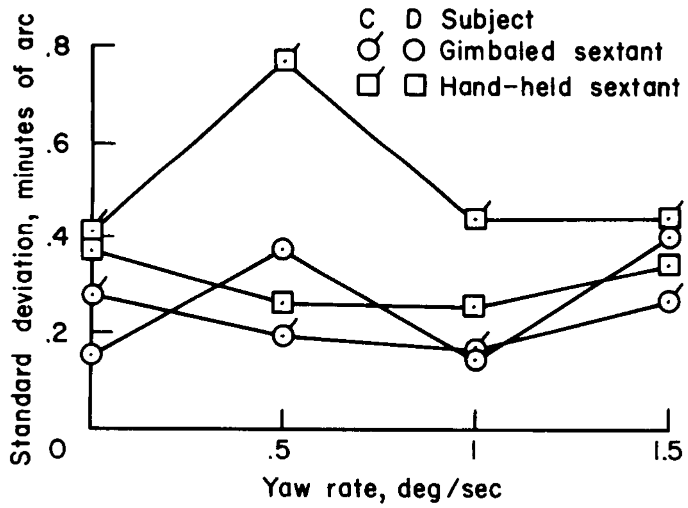


(a) Data from both subjects.

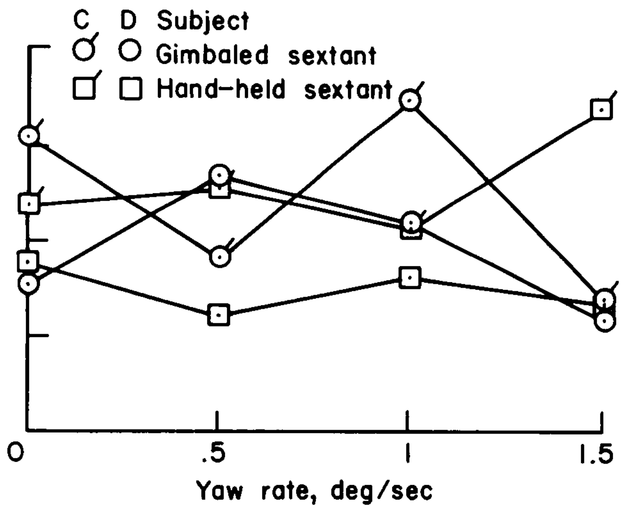


(b) Subject variability averaged.

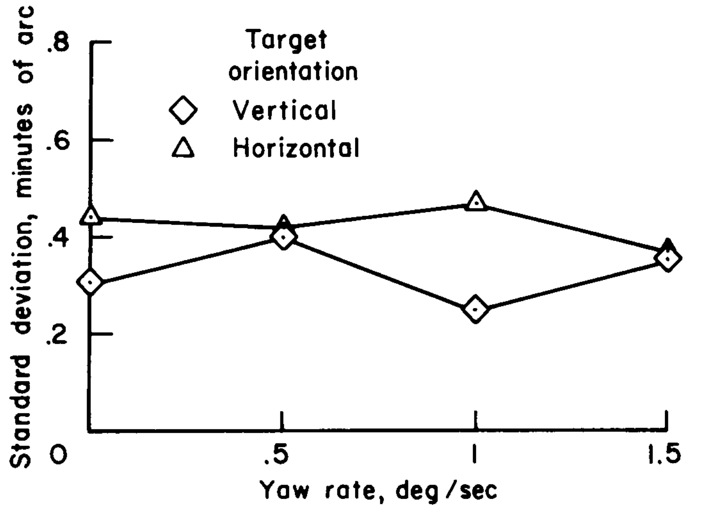
Figure 15.- Variation of standard deviation with an increase in yawing rates both gimbaled and hand-held sextants.



(a) Vertical measurement plane.

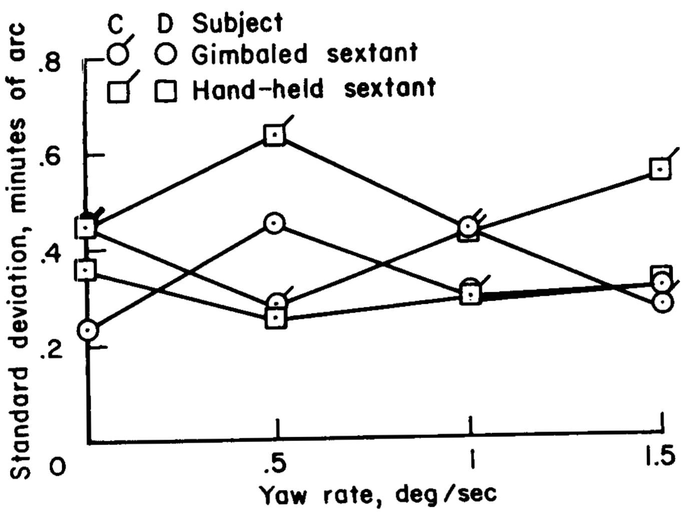


(b) Horizontal measurement plane.

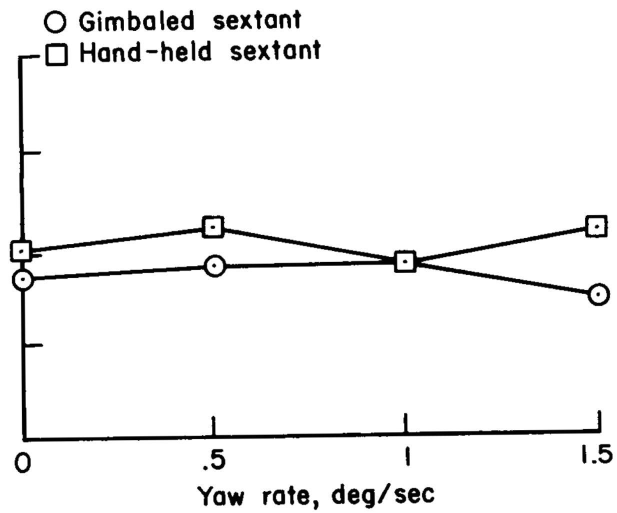


(c) Effects of target orientation.

Figure 16.- Variation of standard deviation with an increase in yawing rate, subjects C and D, limit cycle amplitude = 2°.

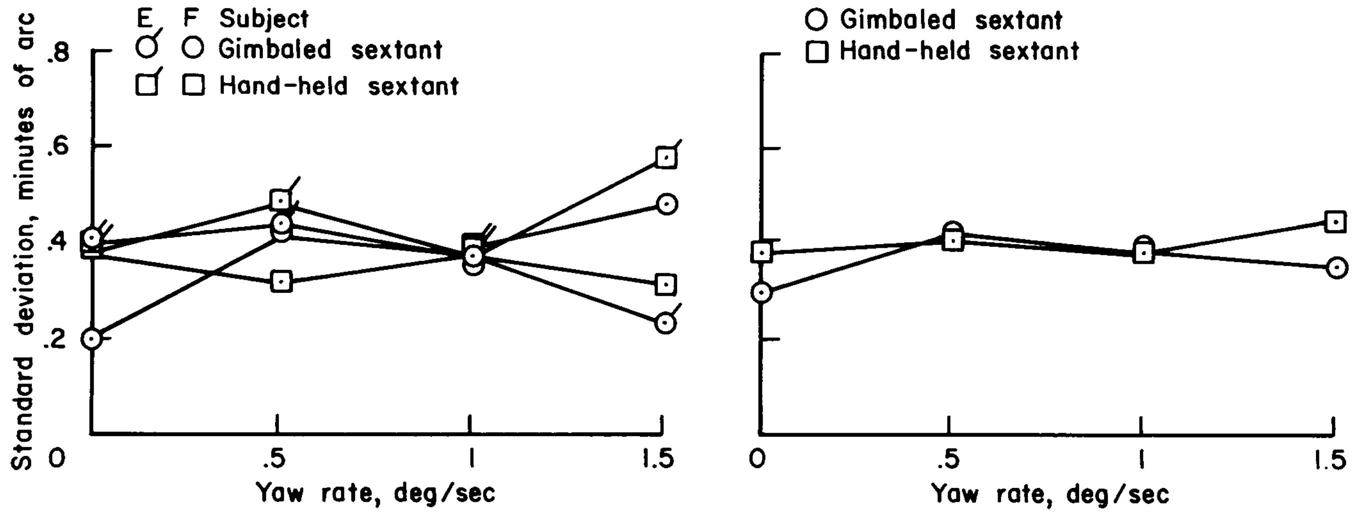


(d) Average value from both star combinations.



(e) Average value of star and personnel combinations.

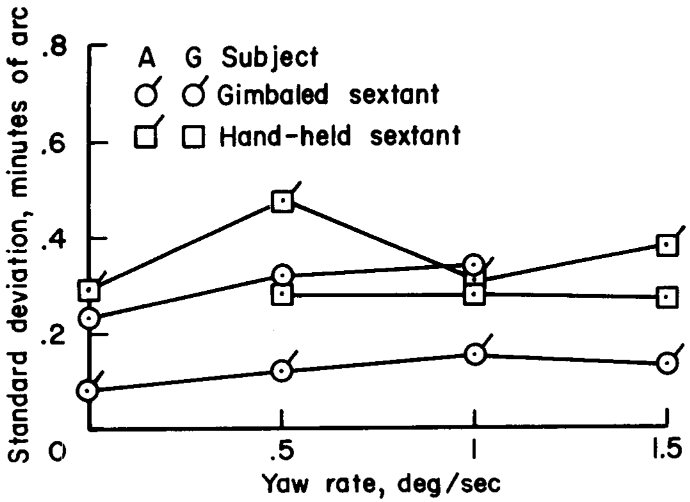
Figure 16.- Concluded.



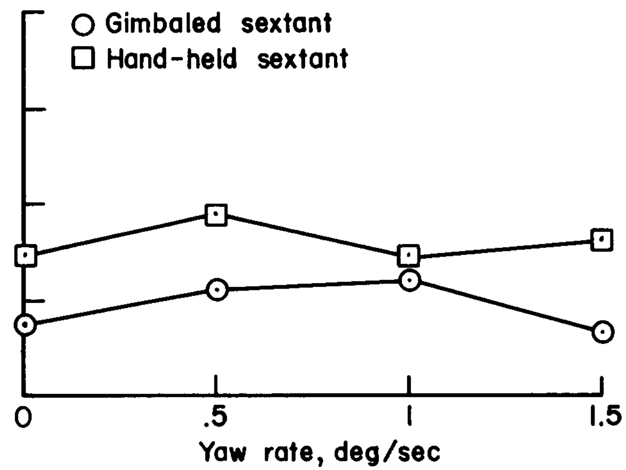
(a) Data from both subjects.

(b) Subject variability averaged.

Figure 17.- The variation of the standard deviation with an increase in yawing rate, subjects E and F, limit cycle amplitude = 2°.



(a) Data from both subjects.



(b) Subject variability averaged.

Figure 18.- The variation of the standard deviation with an increase in yawing rate, subjects A and G, limit cycle amplitude = 2^{o}.

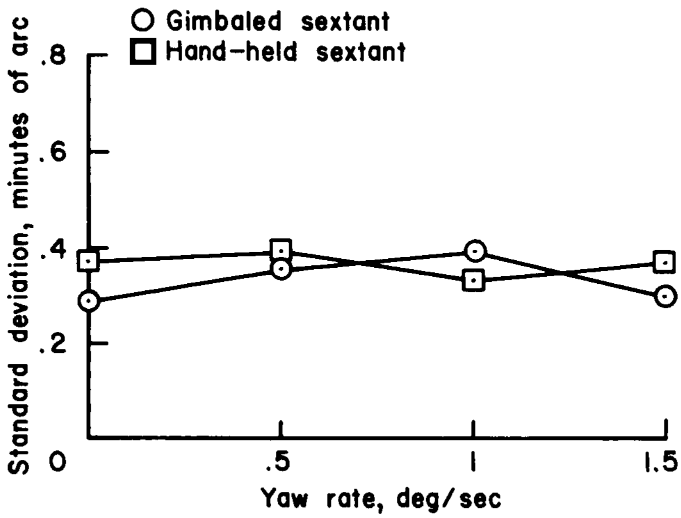
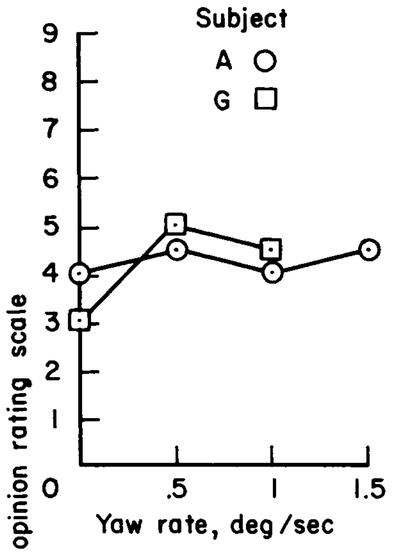
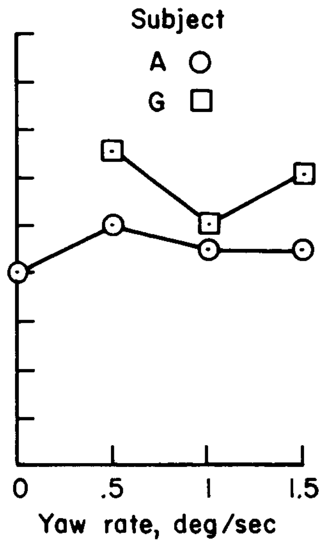


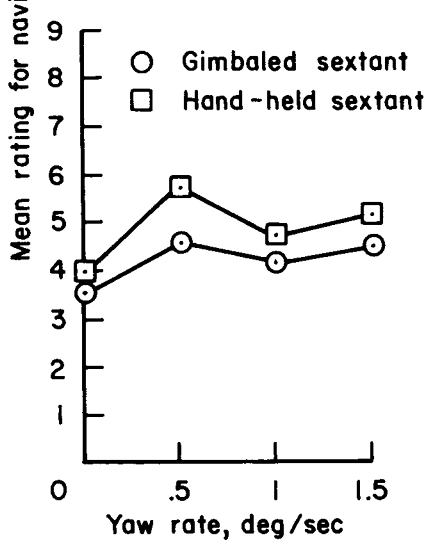
Figure 19.- Summary of data showing variation of standard deviation with increase in yaw rate.



(a) Gimbaled sextant.



(b) Hand-held sextant.



(c) Mean rating of both navigators.

Figure 20.- The variation of subject opinion with an increase in yawing rate.

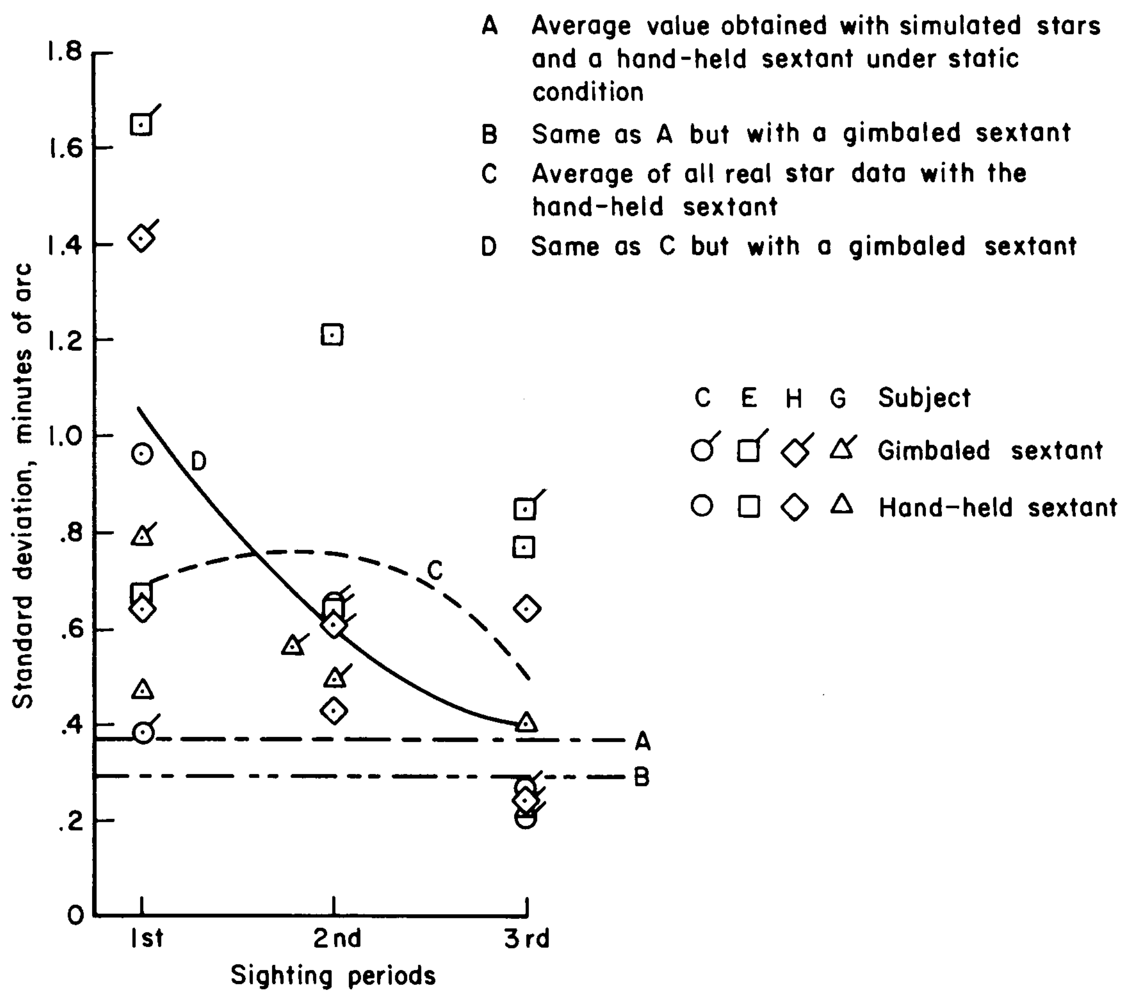


Figure 21.- Results from real star sextant sightings showing the variation of the standard deviation of sighting repeatability for three successive sighting periods.

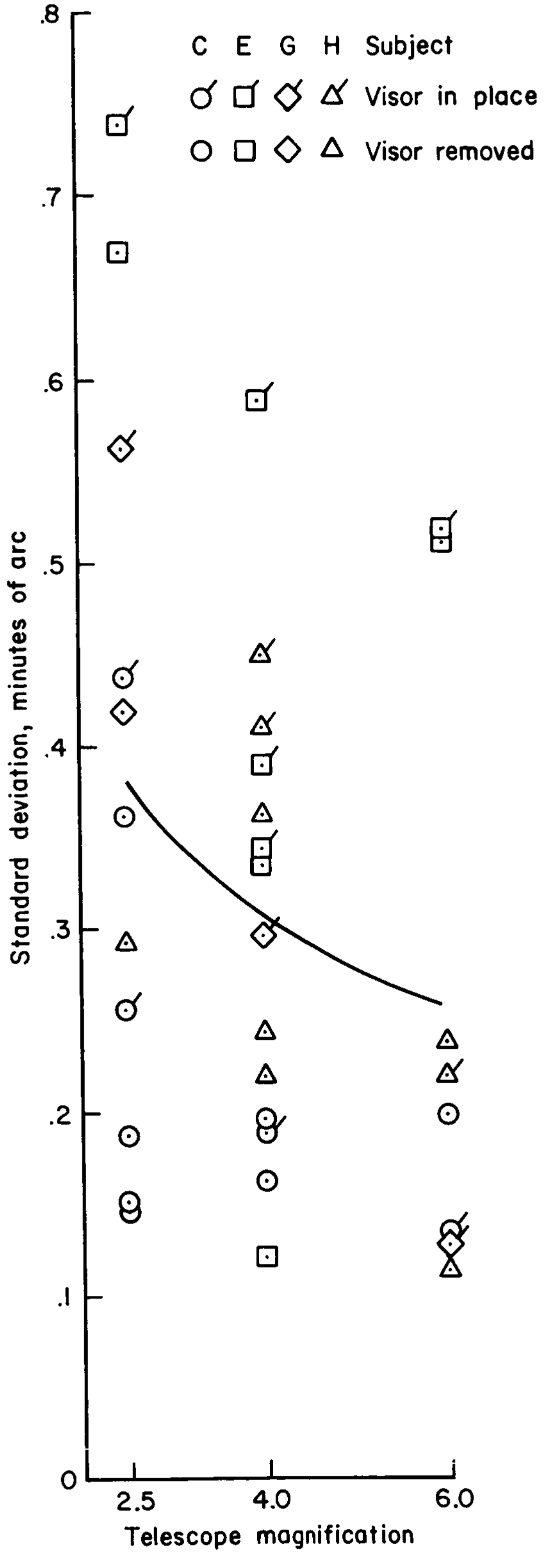


Figure 22.- The variation of the standard deviation of sighting repeatability with sextant telescope magnification.

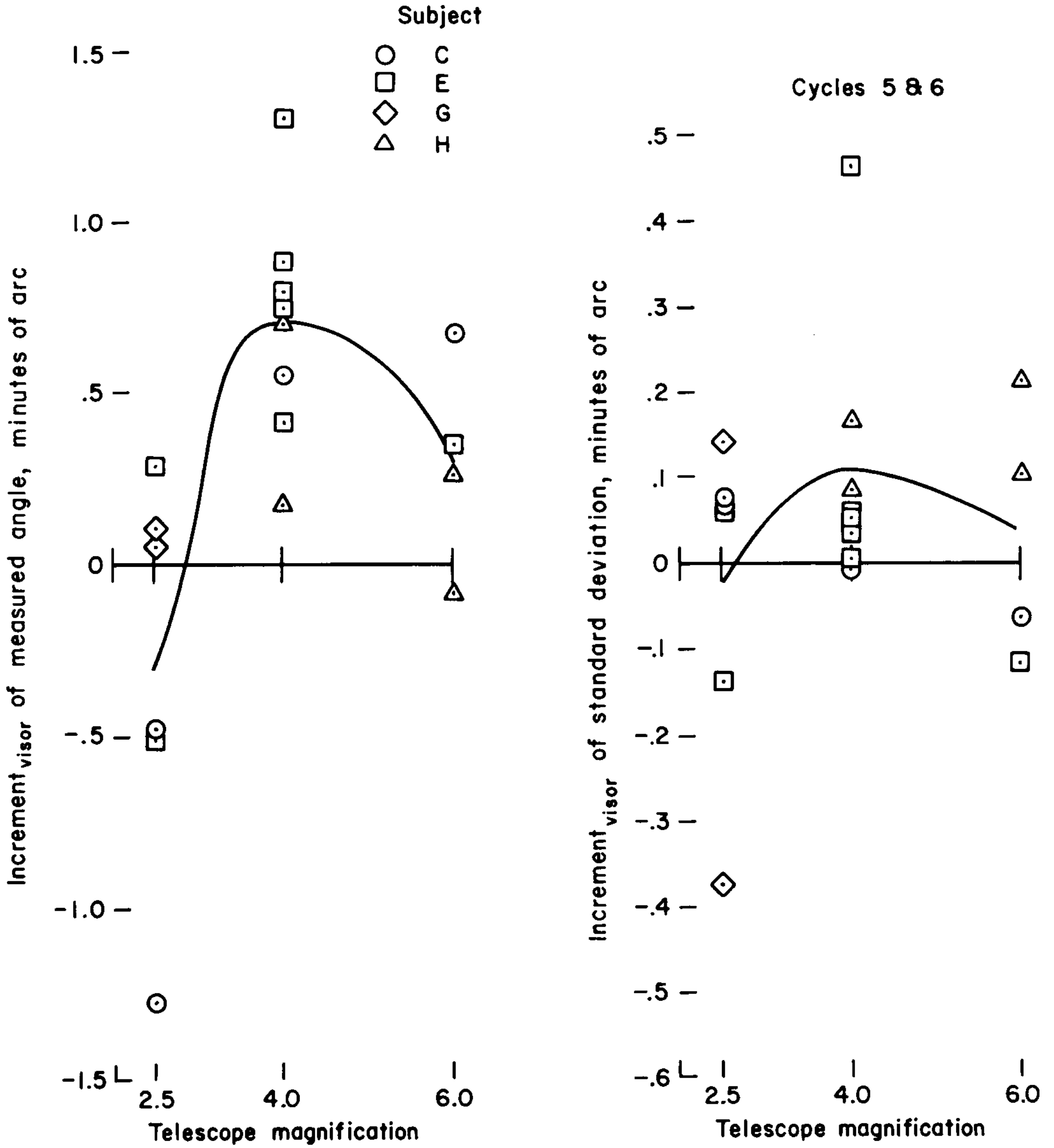


Figure 23.- The variation of incremental effects on the mean measured angle and the standard deviation of the sighting repeatability due to the helmet visor with varied sextant telescope magnification.

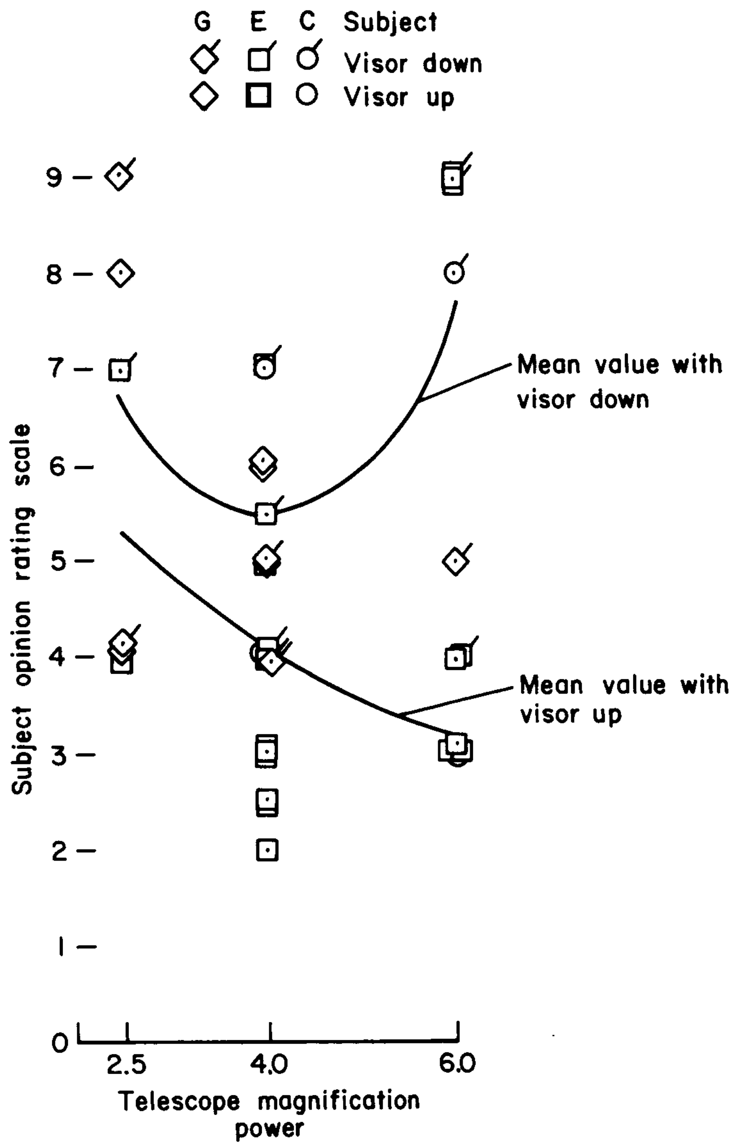


Figure 24.- The variation of subjective opinion with varied sextant telescope magnification.